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**TITLE:** Differentiation of Neonatal Human-Induced Pluripotent Stem Cells to Prostate Epithelial Cells: A Model to Study Prostate Cancer Development

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14. ABSTRACT: In this project we set out to establish conditions for differentiation of human neonatal foreskin skin fibroblast-derived iPSCs into prostate epithelium-like cells and identify differences in gene expression between prostate epithelial cells derived from iPSCs of Caucasian (white) and African-American (black) foreskin fibroblasts. We identified and optimized culture conditions that promote prostate epithelial cell-like differentiation of humaniPS clone, IMAR90-4. Our data show that a feeder layer of urogenital mesenchymal (UGSM) cells from neonatal mouse of either gender in combination with neonatal human dermal fibroblasts induced a striking morphological changes that resembles epithelial differentiation with formation of lumen-like structures. We show requirement of components of the extracellular matrix that promote epithelial-type differentiation. Immunofluorescence and biochemical analyses showed expression of androgen receptor and markers of epithelial differentiation. Analyses of pluripotency marker expression by RT-PCR showed that while human dermal fibroblasts have higher constitutive expression of Nanog, Oct4 and Sox2 compared to UGSM and IMR90 cells. Preliminary studies also showed that black fibroblast population has higher constitutive expression of pluripotency markers than cells from white individuals. These data form the basis for understanding the differences in reprogramming of skin fibroblasts to iPSCs, their differentiation into prostate epithelial cells and susceptibility to transformation.				
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## INTRODUCTION

The ability to distinguish aggressive from indolent prostate cancer requires a better understanding of the biology of prostate epithelial cells. A natural variation in the biology of prostate epithelium is manifest in the markedly different incident rates among men of different races. The incidence of prostate cancer in African-American men is nearly 60% higher with a corresponding 2-3 times higher mortality rate than in Caucasian American males (1-3). The reasons for this disparity are not completely understood. Since no clear patterns were observed for association with dietary factors or life style factors such as physical activity, occupational history, sexual behavior and other health conditions (4), it is likely that inherent genetic (and epigenetic) differences contribute to this difference in prostate cancer risk. Accordingly, efforts are ongoing to search for common risk alleles for prostate cancer risk using genome-wide association studies (5-9).

While identification of individuals/population at risk is useful, these studies do not provide insight into the reasons for these differences in susceptibility of prostate epithelial cells to malignant transformation. Genetically altered mouse models, although very powerful for dissecting roles of specific genes and signaling pathways in intact animal (10-13), have limited utility for understanding differences in disease susceptibility in humans. More recent strategies to study prostate development, maturation and carcinogenesis included differentiation of human embryonic stem cells (hESC) using rodent mesenchyme (14, 15). Studies using hESC also have many limitations including ongoing ethical debate and the number of available cell lines. Therefore, novel innovative strategies are needed to model human prostate epithelial cells for understanding the genetic and epigenetic basis of differences in susceptibility to prostate cancer. Induced pluripotent stem cells (iPSCc) offer a useful alternative to hESC. For example, recently, *in vivo* regeneration potential of human iPSC has been documented (16).

We proposed a hypothesis that differentiation of neonatal foreskin fibroblasts-derived iPSCs to prostate epithelial cells is a unique and powerful strategy for studies on prostate cancer. The advantages of this innovative strategy are: 1) human foreskin specimens are discarded tissues that are collected routinely for studies on skin cell types and therefore easy to obtain and pose no ethical concerns; 2) unlimited and ongoing source of tissues from both Caucasian and African-American males; 3) foreskin tissues obtained within days after birth are temporally closest to the fetal tissue; 4) limited or almost no genetic/epigenetic changes due to environmental exposure; 5) ideal source of cells to investigate cell autonomous mechanisms (13, 17) in malignant transformation of prostate epithelial cells derived from Caucasian and African-American males and 6) has the potential to integrate concept in tissue stem cells and cancer stem cells and allows investigation of the contribution of tissue stem cells in prostate cancer development (18, 19).

The specific aims of this application are: 1) to establish conditions that promote differentiation of human neonatal foreskin skin fibroblast-derived iPSCs into cells with characteristics of prostate epithelium *in vitro* and 2) identify differences in gene expression between prostate epithelial cells derived from iPSCs of Caucasian and African-American foreskin fibroblasts.

## KEY RESEARCH ACCOMPLISHMENTS

Towards these objectives, using the established human iPSC clone IMR90-4, we tested the conditions that promote prostate epithelial cell-like differentiation.

### ***Experiment 1: Epithelial differentiation of human iPS cells***

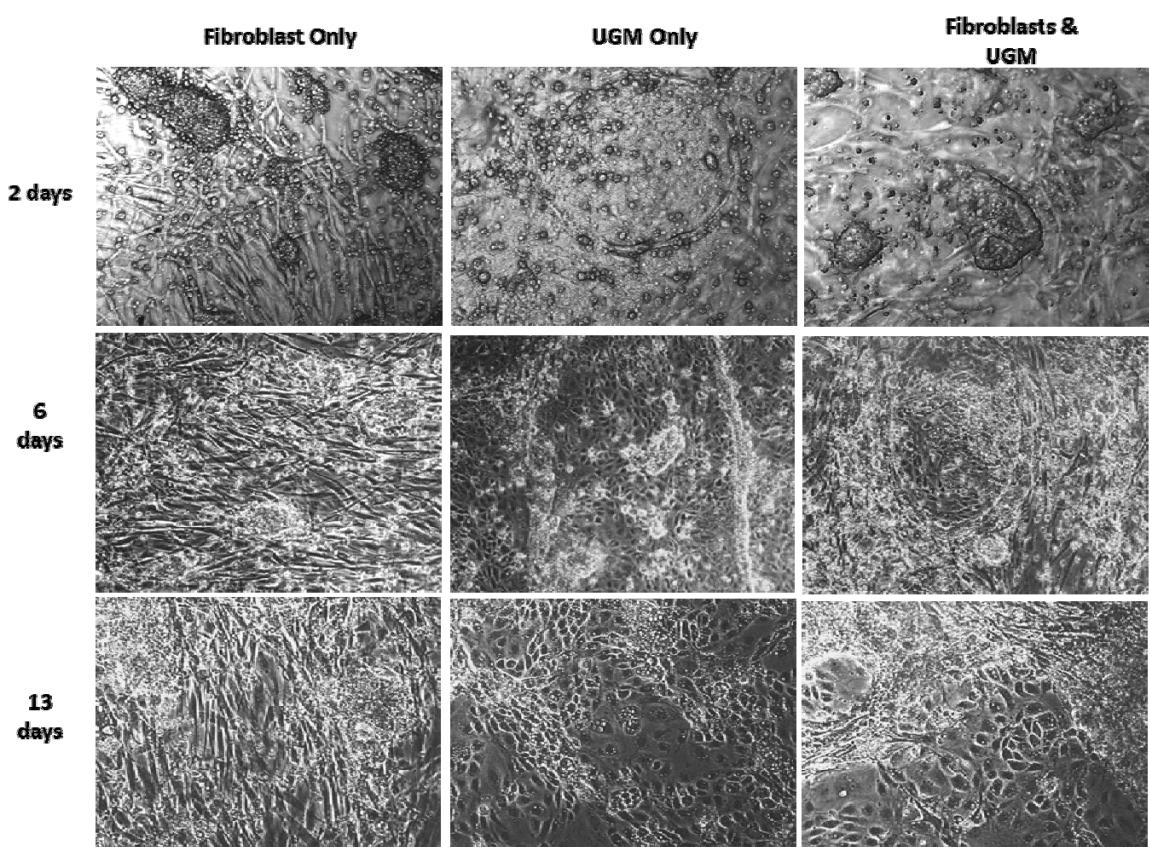
Mouse urogenital mesenchyme cells were chosen as a component of the feeder layer due to their previously identified ability to induce differentiation in *in vivo* models (20, 21). Mouse urogenital mesenchyme cells were isolated from 2-5 day old CB57/BL6 mice (Charles River) of unspecified gender according to a protocol previously identified (22) and cultured on polystyrene coated dishes using a medium formulation specified by the same protocol. Dermal fibroblasts were isolated from human neonatal foreskin and cultured using M106 with LSGS (Invitrogen) on polystyrene coated plates with the medium replaced every three days. The IMR90-4 iPSCs (WiCell) were plated from 1:6 split of a confluent well of a Matrigel coated 6-well plate onto the feeder layers the day after the feeder layers were plated. IMR90-4 iPSCs were plated in 6-well plates on a mixed feeder layer of mitomycin treated human dermal fibroblasts and neonatal mouse urogenital mesenchymal cells and cultured in

PrEGM medium (Lonza). The medium was replaced every 3 days. Each cell type (dermal fibroblasts or urogenital mesenchyme cells) was plated at a density of  $2 - 3 \times 10^4$  cells/cm<sup>2</sup> to give a final feeder layer density of  $4 - 6 \times 10^4$  cells/cm<sup>2</sup>. Fig. 1 shows the morphology of the cells in the indicated wells.

#### **Fig. 1: Epithelial differentiation of human iPSCs.**

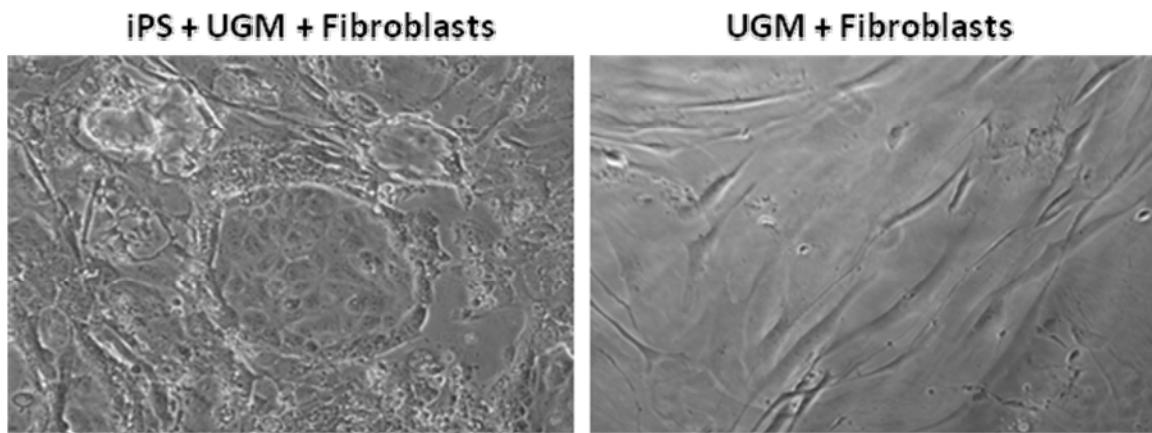
IMR90-4 cells were plated in 6-well plates on a mixed feeder layer of (1:1)

mitomycin treated human dermal fibroblasts and neonatal mouse urogenital mesenchymal cells and cultured in PrEGM medium (Lonza). The medium was replaced every 3 days. Each cell type (dermal fibroblasts or urogenital mesenchyme cells) was plated at a density of  $2 - 3 \times 10^4$  cells/cm<sup>2</sup> to give a final feeder layer density of  $4 - 6 \times 10^4$  cells/cm<sup>2</sup>. The IMR90-4 cells were plated from 1:6 split of a confluent well of a 6 well plate onto the feeder layers the day after the feeder layers were plated. The above images were taken at a 10X magnification.



### ***Experiment 2: Optimization of mouse urogenital mesenchymal cells required for iPSC differentiation***

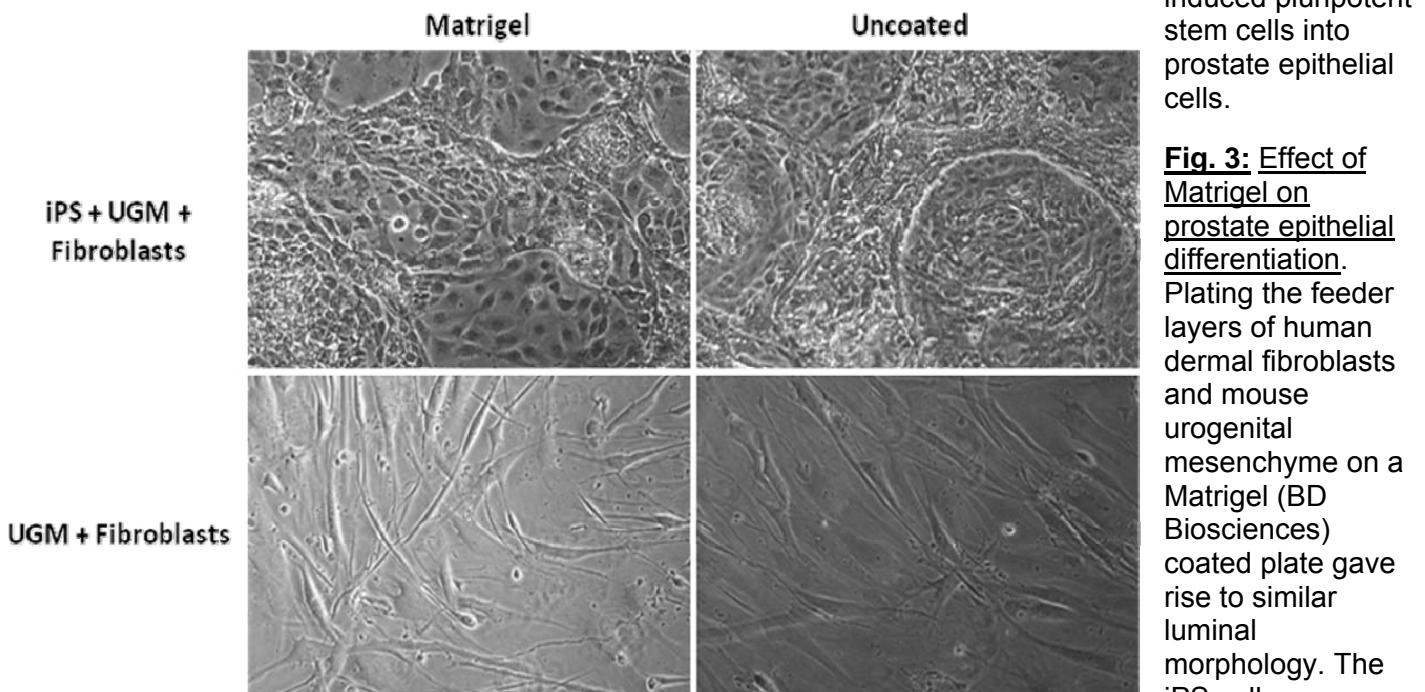
To optimize the number of mouse urogenital mesenchymal cells needed in the feeder layer, we used various ratios of fibroblasts to mesenchymal cells and found that even a 1:3 ratio mesenchymal to fibroblasts was sufficient to induce morphological changes similar to seen in Fig.1



**Fig. 2: Effect of a lower number of mouse urogenital mesenchymal cells in the co-culture feeder layer.** A 1:3 ratio of urogenital mesenchyme cells to dermal fibroblasts used as a feeder layer with IMR-90 iPS cells plated over also showed luminal morphology, suggesting that a lower number of urogenital mesenchyme cells can be used to induce differentiation. The feeder layers were mitomycin treated and plated at a density of  $4 - 6 \times 10^4$  cells/cm<sup>2</sup> into a 6-well plate with three times as many dermal fibroblasts as mouse urogenital mesenchyme cells. IMR90-4 iPS cells were plated from one well of a confluent 6 well plate split 1:6 into the 6 well plate. The medium used was PrEGM (Lonza) and was replaced every three days. The above images were taken at 10X magnification 5 days after plating the iPS cells.

#### **Experiment 3: Effect of extracellular matrix (Matrigel) on prostate epithelial differentiation.**

The purpose of this experiment was to optimize the *in vitro* cell culture system by which to differentiate human induced pluripotent stem cells into prostate epithelial cells.

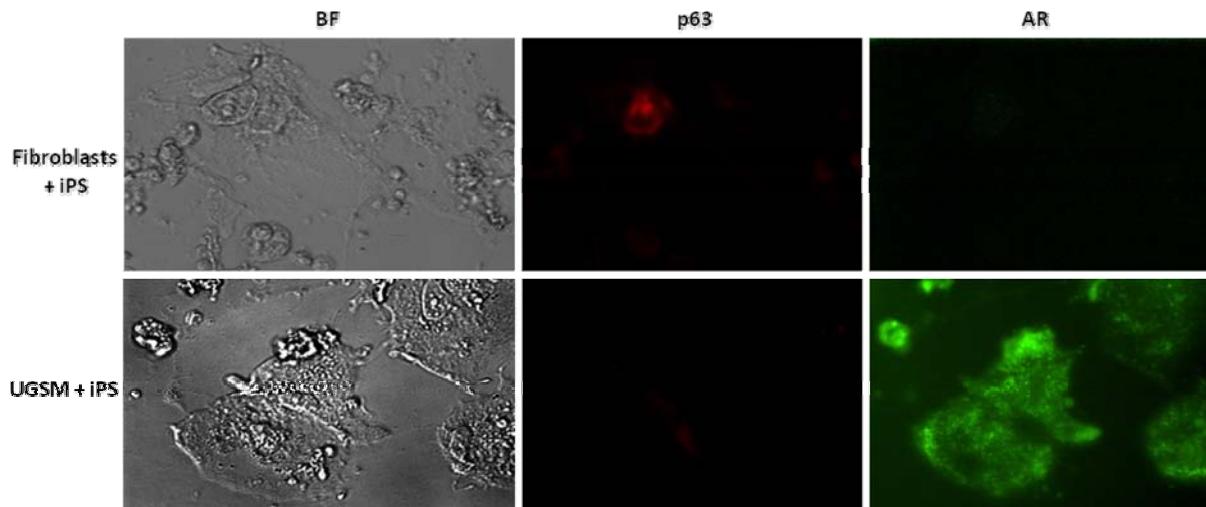


Plated over the feeder layers the day after the feeder layers were plated and prostate medium (PrEGM, Lonza) was replaced every three days. A 1:3 ratio of urogenital mesenchyme cells to dermal fibroblasts was used as a feeder layer at a density of  $4 - 6 \times 10^4$  cells/cm<sup>2</sup> in a 6 well plate with three times as many dermal fibroblasts

as mouse urogenital mesenchyme cells. The images above were taken 5 days after plating the iPS cells at a magnification of 10X.

#### **Experiment 4: Evaluation of expression of epithelial differentiation markers by human iPSC**

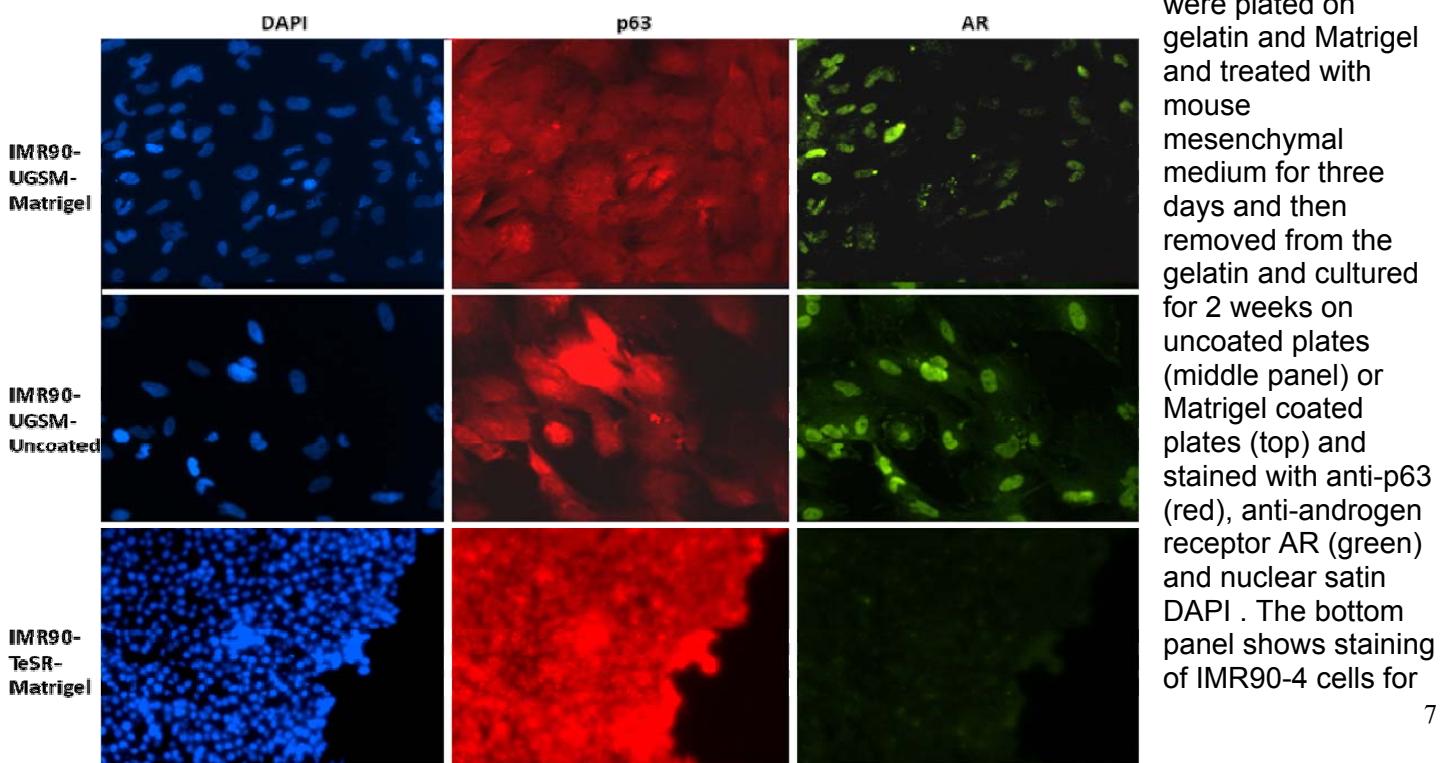
The purpose of this experiment was to study the expression of different prostate specific markers and the effects of each component of the feeder layer on the iPS cell differentiation.



**Fig. 4: Immunofluorescence of co-cultures shows effect of each cellular component of the co-culture on the differentiation of iPS cells.** The top panels show immunofluorescence staining of iPS cells plated over mitomycin treated human dermal fibroblasts derived from white neonatal foreskin, cultured in PrEGM (Lonza). The bottom panels show immunofluorescence staining of iPS cells plated over mitomycin treated mouse urogenital mesenchyme and cultured in PrEGM (Lonza). Pictured left to right a) cells imaged in bright field, b) stained for p63 (red) and c) androgen receptor (green). All primary antibodies were obtained from Santa Cruz Biotechnology and secondary antibodies were obtained from Invitrogen.

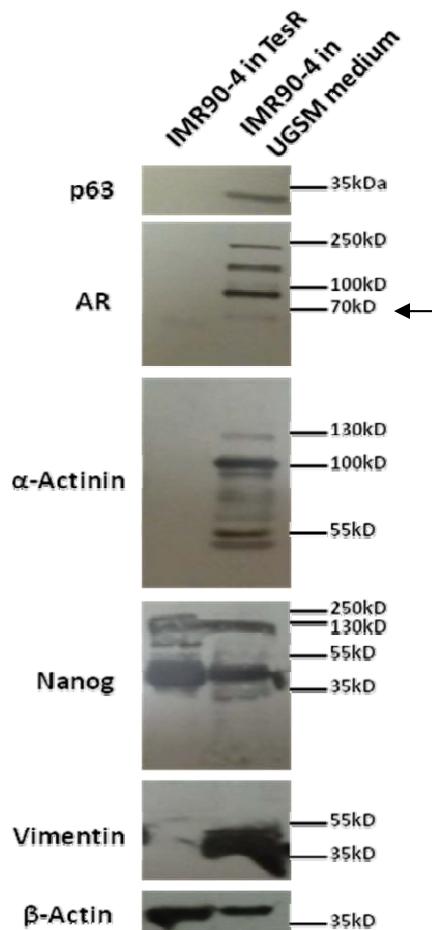
#### **Experiment 5: Expression of prostate markers in human iPS cells treated with mesenchyme medium.**

**Fig. 5: Expression of prostate markers in human iPS cells treated with mesenchyme medium.** IMR90-4 cells were plated on gelatin and Matrigel and treated with mouse mesenchymal medium for three days and then removed from the gelatin and cultured for 2 weeks on uncoated plates (middle panel) or Matrigel coated plates (top) and stained with anti-p63 (red), anti-androgen receptor AR (green) and nuclear stain DAPI. The bottom panel shows staining of IMR90-4 cells for



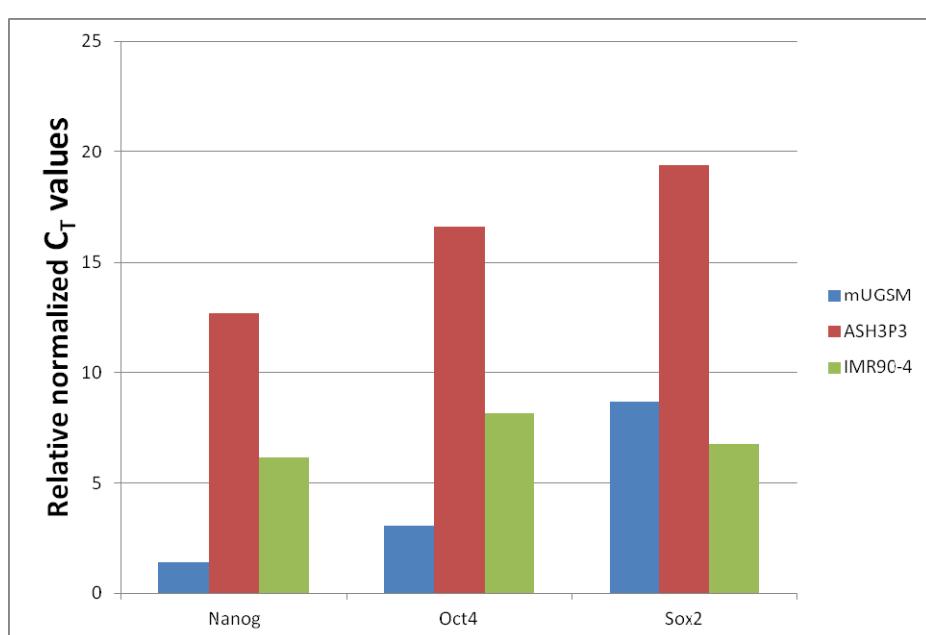
the same antibodies. All primary antibodies were obtained from Santa Cruz Biotechnology and secondary antibodies were obtained from Invitrogen.

#### Experiment 6: Biochemical analysis of differentiation of human iPS cells



**Fig. 6: Expression of prostate markers in IMR-90 iPS cells treated with mesenchyme medium.** Western blot of lysate from IMR90-iPS cells cultured in TeSR medium on Matrigel coated 6 well plates (left) and IMR90-iPS cells plated on a gelatin coated 6 well plate and cultured in urogenital mesenchyme medium for three days followed by plating on an uncoated plate and culturing for 2 weeks (right). The cells were harvested by EDTA treatment followed by scraping the plate with the large end of a p1000 pipette tip. 25 $\mu$ g of protein was loaded from each sample onto 9% and 12% polyacrylamide gels to probe for markers p63, androgen receptor, alpha-actinin and vimentin.

#### Experiment 7: RT-PCR analysis of expression levels of pluripotency markers

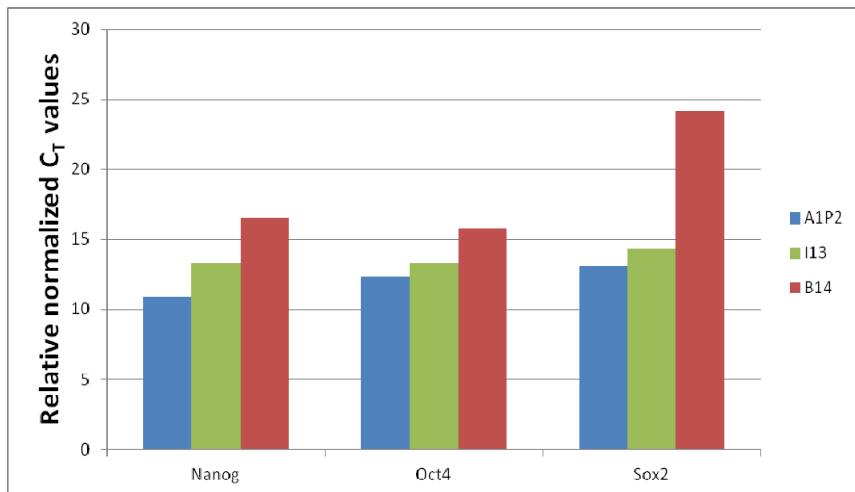


**Fig. 7: Relative expression levels of pluripotency markers in component cell lines.** The expression levels of pluripotency markers as analyzed by q-RT-PCR. RNA was isolated from mouse urogenital mesenchyme (mUGSM), white dermal fibroblasts (ASH3P3, and IMR90-4 induced pluripotent stem cells (using the 5 prime PerfectPure RNA Cell and Tissue Kit) and used to analyze the baseline expression levels of all pluripotency markers. cDNA was synthesized from isolated RNA using the GoScript Reverse Transcriptase system. Power SYBR reagents were used to perform the PCR and the primers were ordered from IDT. The C<sub>T</sub> values were

normalized by subtracting the GAPDH mean  $C_T$  value for each sample from the  $C_T$  value obtained for the gene of interest for each sample.

### **Experiment 8: Characterization of skin fibroblast for expression levels of pluripotency markers**

In order to understand the differences in constitutive levels of expression of pluripotency markers in fibroblasts derived from individuals of different genetic ancestry, we performed RT-PCR analysis of pluripotency markers



**Fig. 7: Relative expression levels of pluripotency markers in fibroblast of different genetic ancestry.** The expression levels of pluripotency markers as analyzed by q-RT-PCR. RNA was isolated from dermal fibroblasts cultured from white Caucasian (A1P2), Indian subcontinent (I13), and black African-American (B14) neonatal foreskin. 5 prime PerfectPure RNA Cell and Tissue Kit were used to analyze the baseline expression levels of all pluripotency markers. cDNA was synthesized from isolated RNA using the GoScript Reverse Transcriptase system. Power SYBR reagents were used to

perform the PCR and the primers were ordered from IDT. The  $C_T$  values were normalized by subtracting the GAPDH mean  $C_T$  value for each sample from the  $C_T$  value obtained for the gene of interest for each sample.

### **REPORTABLE OUTCOMES:**

We have established the cell culture parameters for differentiation of human iPS cells to cells that express epithelial cell markers and androgen receptor.

### **CONCLUSIONS**

Our data show that human fibroblast-derived iPS can be differentiated to a cell type that expresses both markers of epithelial and prostate-like differentiation. Additionally, our data also suggest that fibroblasts derived from neonatal African-American skin show higher constitutive expression of pluripotency markers.

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## Review Article

# Cancer stem cells and tumor transdifferentiation: implications for novel therapeutic strategies

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**Abstract:** Highly malignant tumors mostly consist of rapidly proliferating cells. However, tumors also contain a few cells in a quiescent state that can be characterized as slow-cycling, expressing markers of stem cells and possessing the ability to initiate new tumors. These quiescent cells, now generally termed 'cancer stem cells' (CSC) (or 'cancer initiating cells'), are capable of regenerating the entire tumor—as it occurs in metastatic spread. This process of tumor initiation by stem-like cells presumably involves differentiation of quiescent CSC into rapidly proliferating tumor cells. An important implication of the presence of slow cycling, quiescent stem-like cells in the tumor and their ability to initiate tumors is that they contribute to the resistance to treatments by conventional chemo- and radiotherapy directed toward killing rapidly dividing cells. However, similar to normal stem cells, the CSC could also potentially transdifferentiate into cell lineages other than the original lineage from which the tumor arose. Therefore, transdifferentiation of CSC offers a possible therapeutic strategy which has not yet been fully exploited. In this article, we provide a comprehensive review of the concepts in tumor cell transdifferentiation and discuss the mechanisms of transdifferentiation with emphasis on their relevance to potential novel treatment strategies.

**Keywords:** Cancer stem cells, transdifferentiation, CSC-targeted therapy, tumor Initiating cell, EMT

## Introduction

Cancers are a population of genetically compromised cells that proliferate without control [1]. Targeting rapidly proliferating cells is the rationale behind many conventional cancer therapies. However, these therapies are rarely as successful in the long run as those instances where tumors that can be surgically resected. Chemo- and radiation therapy failure is thought to occur due to the well-recognized tumor heterogeneity, which allows a subpopulation of tumor cells to escape cell death [1].

The clonal evolution model of tumorigenesis suggests that cancer begins with a single transformed cell whose progeny, through subsequent rounds of cell division, acquire mutations that further increase their own malignant potential [2]. According to this model, every cell within a cancer should be able to generate an entire new tumor independent of all other cells within the original tumor. However, it has been

shown that only a small fraction of cells within a tumor mass is capable of initiating new tumors [3-5]. Therefore, for metastasis to occur, cells that have the ability to initiate the tumor must reach a suitable destination within the body. These tumor initiating cells must also be able to self-renew to create a population of additional tumor initiating cells within the metastatic lesion. This ability to self-renew also defines stem cells. Such cells with "stem-like" and "tumor initiating" properties are now called "cancer stem cells" (CSC) [6].

## Cancer stem cell model

Based on similarities observed between certain cancer cells and embryonic cells, Julius Cohnheim first proposed in 1875 that cancers arise from "embryonic rests," cells leftover from embryogenesis [7]. However, it is only within the past decade, experimental evidence for the concept of cancer stem cells has begun to accumulate [8].

The CSC model defines a hierarchy among cancer cells such that only a small subset is capable of sustaining the tumor and establishing the cellular heterogeneity [6]. CSC exhibit the quintessential stem cell properties of self-renewal and differentiation. There is some evidence that CSC originate from normal tissue stem cells [9, 10]. It has also been demonstrated that CSC can arise from spontaneous dedifferentiation of tumor cells [11, 12]. A third possibility is that suggested originally by Cohnheim, namely that remnants [of pluripotent stem cells] from embryogenesis could acquire malignant properties and contribute to CSC [7]. The above mechanisms may not be mutually exclusive.

Additionally, mechanisms for generating and maintaining CSC appear to also depend on the microenvironment of the tumor [13-17]. The microenvironment plays a major role in preserving the CSC population and in their self-renewal [13]. For example, in primary colorectal cancers stromal myofibroblasts secrete hepatocyte growth factor (HGF), which enhances WNT signaling in neighboring cancer cells and thereby induces stem cell features such as self-renewal in CSC [14]. Endothelial cells were shown to contribute to CSC microenvironment in glioblastoma by providing Notch ligands that facilitate self-renewal [15]. Even transient contact between circulating tumor cells and platelets seems to induce a epithelial mesenchymal transition (EMT) program that causes tumor cells to become CSC [16]. Finally, metastasized CSC arriving in a distant organ can reprogram stromal cells to suit their needs [17].

The CSC model also offers an explanation for the notorious resistance of cancers to conventional chemo- & radiation therapy [18-20]. These therapeutic approaches target the highly proliferative tumor cells, whereas CSC that are quiescent escape killing. [19]. Stresses like hypoxia, nutrient starvation, and inflammation can cause CSC to leave their quiescent state and re-enter the cell cycle. This provides a window of tumor vulnerability to conventional therapies [21]. For example, treatment of acute myelogenous leukemia (AML) stem cells with granulocyte colony stimulating factor (G-CSF) was reported to allow CSC to leave their dormant state [22]. Inhibition of either PML or FOXO, molecules involved in TGF $\beta$  signaling, in chronic myelogenous leukemia (CML) stem

cells also seems to permit CSC to leave their quiescent state and become susceptible to Imatinib treatment [23, 24]. Therefore, while the CSC model of cancer provides valuable insights into tumorigenesis it also has consequences for disease management.

CSC normally differentiate into dividing tumor cells, and they can also differentiate into structures that support the tumor and its propagation. Transdifferentiation, a process by which tumor cells or CSC acquire features of different cell lineages, could either attenuate the tumor's malignant potential, or allow development of structures that support the tumor's aggressive behavior. CSC transdifferentiation also offers an opportunity for cancer treatment. Differentiating CSC into post-mitotic, terminally differentiated cells offers the potential to abolish the ability of a tumor to recapitulate itself from CSC. We feel this strategy has been inadequately investigated. In this review we provide a rationale for transdifferentiation as a therapeutic option for cancer using examples of selected malignancies.

### Markers of CSC

Although each type of cancer may have CSC markers that are specific to that tumor (for example, CD271, in melanoma stem cells [25, 26]); there are a few "pan" CSC markers that are expressed in a range of distinct malignancies. While these markers are highly relevant for studies on the biology of CSC, they also could serve as useful markers to monitor efficacy of differentiation therapy. The prominent among these are CD34, CD133, CD44, EpCAM, and ALDH [6, 27-29]. CD34, one of the first CSC markers to be described [30] is a hematopoietic stem cell marker that is well characterized in acute myeloid leukemia stem cells. Similarly, CD133 has also been widely investigated as a CSC surface marker since its identification as a marker of glioblastoma multiforme stem cells [31]. CD133 has since been described in CSC from osteosarcoma, Ewing's sarcoma, endometrial, hepatocellular, colon and lung carcinomas and ovarian and pancreatic adenocarcinoma [32-35]. CD44 is present in head and neck cancer, prostate, gastric and colorectal carcinoma stem cells [36]. EpCAM is a marker of colon carcinoma and pancreatic adenocarcinoma stem cells [37]. ALDH has been used to identify CSC in melanoma, colorectal, breast, prostate and

squamous cell carcinomas, pancreatic adenocarcinoma, and osteosarcoma [38, 39].

Melanoma has received much attention with regard to existence and frequency of CSC. This tumor contains a high proportion of tumor initiating cells (upto 50%) with a wide spectrum of CSC markers (e.g., CD133, CD271, ALDH1, JARID1B) [5, 38, 40, 41]. Because these “melanoma stem cells” (MSC) are sometimes so numerous, some have argued that the CSC model may not apply to melanoma [40]. There are data from two groups indicating that melanoma lesions contain a CSC subset characterized by CD271 expression [25, 26]. In a severely immunodeficient strain NOD-SCID-IL2R $\gamma$ <sup>-/-</sup> mice, both (CD271 + and -) subsets were found to be tumorigenic. However, the CD271 $^{-}$  fraction did not recapitulate the original tumor histology [26]. It was also reported that many CD271 $^{-}$  melanoma cells display MSC qualities, implying that not all MSC display the same surface marker [40]. A possible limitation in this study was that cells were trypsinized prior to assessing tumorigenesis, which could have destroyed CD271 marker resulting in underestimation of CD271 positivity [6]. The frequency of MSC can vary widely from 2.5% to 41% based on the approach used to assess their tumorigenic potential [25].

Moreover, other studies have suggested that the ability of melanoma cells to transition between invasive and proliferative states as governed by prevailing tumor microenvironment (so-called “phenotype switching”) may entirely explain metastasis in melanoma [42]. This cellular property of phenotype switching may explain how a normal melanocyte gives rise to melanoma through de-differentiation [42]. A way to reconcile phenotype switching with cancer stem cell model might be that this intrinsic plasticity of cancer cells in response to microenvironment is primarily a property of CSC [43]. That is, only CSC can “switch phenotypes”. This concept requires further investigation.

Regardless of the debate over the existence of CSC, tumor transdifferentiation still presents an attractive therapeutic opportunity. Coaxing cancer cells to transition to a post-mitotic, terminally differentiated state could significantly attenuate tumor progression.

### Modulating differentiation of CSC as a therapeutic approach

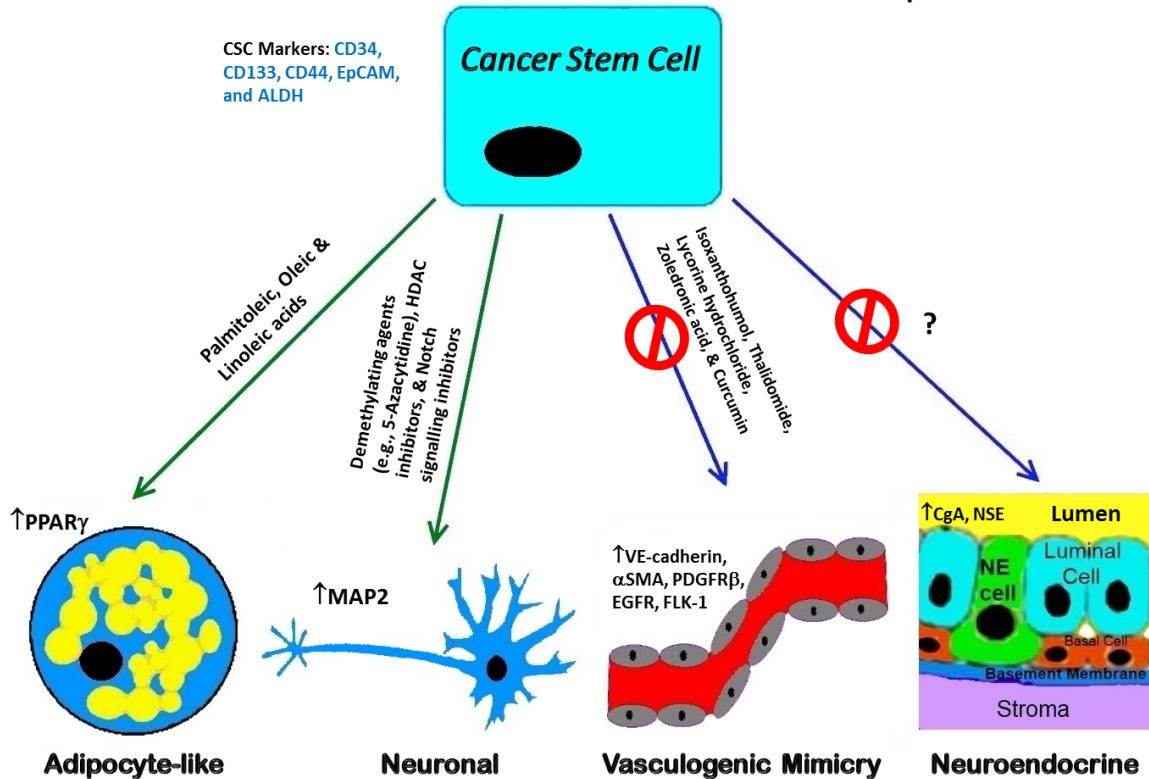
A question of practical importance with respect to the plasticity of differentiation of CSC is: what are the mechanisms that regulate the cellular fates of CSC? CSC transdifferentiation through pharmacologic intervention offers a promising adjunct to conventional chemotherapy. For example, a differentiation therapy approach using all trans-retinoic acid (ATRA) for the treatment of acute promyelocytic leukemia (APL) has shown some promise [44]. This leukemia differentiates into mature granulocytes after ATRA treatment. Melanoma is one of the most studied cancers with respect to transdifferentiation of CSC. It was reported that CSC in melanoma formed spheroids in culture [45]. When grown under varying kinds of differentiation media, these spheroids could be transdifferentiated into melanocytes, adipocytes, chondrocytes, or osteocytes. Melanoma cells from these spheroids showed increased potential to form tumors *in vivo* after injection into mice. These studies highlight both the concept of CSC in melanoma and the ability of melanoma CSC to undergo transdifferentiation producing diverse cell lineages [45]. Surprisingly, there is currently no FDA approved cancer treatment regimen based on transdifferentiation. Nonetheless, considerable accumulating data point to the validity and potential of this approach (see **Figure 1** and subsequent sections).

#### Neuronal differentiation

Expression of neuronal proteins and neuron-like differentiation has been long recognized in neoplastic melanocytes [46, 47]. Certain melanoma cell lines that express CSC markers CD133 and ABCG2 [48] also express neuronal progenitor and mature neuronal/oligodendrocyte markers (including MAP2, a marker of post-mitotic neurons) and are able to transdifferentiate into astrocytes under specific growth conditions. Microtubule associated protein 2 (MAP2) is highly expressed in benign melanocytic nevi and early primary melanoma but not in metastatic melanoma [49, 50]. More importantly, forced expression of MAP2 in metastatic melanoma cells inhibits their growth [50].

Cellular differentiation is a highly complex process that includes epigenetic modifications

## Modulation of CSC Transdifferentiation: Potential Therapeutic Avenues



**Figure 1.** Potential therapeutic avenues to modulate transdifferentiation of cancer stem cells. CSC express various protein markers and are resistant to conventional therapies. Green arrows depict transdifferentiation of CSC into post-mitotic cells, and agents that facilitate these processes are listed. For example, unsaturated fatty acids may drive CSC into terminally differentiated adipocyte-like cells. Similarly, DNA demethylating agents could help melanoma CSC transdifferentiate into neuronal cells. Undesirable types of transdifferentiation are depicted with blue arrows. CSC can transdifferentiate to generate vascular conduits by a process termed "vasculogenic mimicry". A number of agents, tested mostly *in vitro*, but some in animal models, have been shown to prevent this process and need further investigation. Prostate CSC transdifferentiation into neuroendocrine (NE) cells is associated with worse prognosis owing to transition to androgen independence. Therefore, inhibition of NE differentiation of prostate CSC may be desirable. For simplicity, transdifferentiation of small cell lung cancer (SCLC) into NE cells and epithelial-mesenchymal transition (EMT) are not shown.

allowing activation of lineage specific factors and repression of stem cell (or precursor cell) factors [51]. Not surprisingly, epigenetic modifications are also reported to regulate tumor cell transdifferentiation [52]. For example, the regulatory sequences of the neuronal marker gene, MAP2, are progressively methylated during melanoma progression, suggesting MAP2 expression is silenced by epigenetic mechanism in metastatic melanoma [53]. Treatment of metastatic melanoma cells with 5-azacytidine induced MAP2 expression [54]. Thus, treatment with demethylating agents such as 5-azacytidine may be useful for melanoma, if used in appropriate combination with other agents [26]. A phase II clinical trial of 5,6-dihydro-5-azacytidine (DHAC) showed limit-

ed benefit in malignant melanoma without the side-effect of myelosuppression [55]. Another phase I trial of 5-aza-2'-deoxycytidine (decitabine) plus high dose intravenous interleukin-2 showed regression of melanoma in 31% of patients with significant incidence of neutropenia [56]. In neither trial, the contribution of neuronal (or other) transdifferentiation of melanoma CSC to the anti-tumor effect of the demethylating agent was investigated.

Additionally, histone deacetylase (HDAC) inhibitors have been shown to activate MAP2 expression and induce benign neuron-like differentiation in a metastatic melanoma mouse cell line [57]. HDAC inhibitors also inhibit the growth of uveal melanoma cells both *in vitro* and *in vivo*

and induce melanocyte/neuron-like differentiation of melanoma cells as evidenced by dendritic arborization [58].

It has also been demonstrated that inhibition of Notch signaling upregulates MAP2 gene expression in melanoma through epigenetic mechanism [54]. It is known that Notch signaling is essential to maintenance of neuronal stem cells (NSC) and Notch inhibition results in NSC neuronal differentiation [59]. Thus, Notch inhibition may inhibit melanoma tumor progression through CSC neuronal transdifferentiation. In a recent study, it was shown that treatment with a novel  $\gamma$ -secretase inhibitor (an inhibitor of Notch signaling) reduces tumor initiating potential of melanoma both *in vitro* and *in vivo* [60]. An interesting observation here is that a signaling mechanism that induces differentiation of a normal tissue stem cell-type also appears to be a potential approach to induce transdifferentiation of tumor cells and CSC into post-mitotic cells. Hence, there could be other candidate pathways of tissue stem cell differentiation that could be exploited in a similar fashion.

It was reported more than a decade ago that neoplastic melanocytes express p75NGFR, CD56/NCAM, and GAP-43, markers that are specific to Schwann cell precursors (SCP), but not mature Schwann cells [47]. Specifically, these Schwann precursor-like neoplastic melanocytes were present in melanocytic nevi, which are thought to be precursor lesions to melanoma [47]. Interestingly, these SCP markers are present in only less than 20% of melanomas and they are never present together [47]. It is tempting to speculate that such melanomas arise from aberrant differentiation of SCP. Support for such possibility came recently when it was demonstrated that SCP not only share markers with neoplastic melanocytes, but SCP indeed are the source for melanocytes in the skin [61]. Therefore, it is conceivable that driving melanoma transdifferentiation toward a neuronal phenotype could serve as therapeutic strategy to deplete the pool of CSC in this cancer.

### Neuroendocrine differentiation

Much like normal prostate stem cells, prostate cancer stem cells (PCSC) can also give rise to luminal secretory epithelial cells as well as ter-

minally differentiated neuroendocrine (NE) cells [62, 63]. In addition, in prostate cancer, cancerous luminal secretory cells may directly transdifferentiate into NE cells suggesting existence of alternative mechanism for generating this unique population. A higher proportion of NE cells in prostatic tumors is associated with more aggressive behavior and worse prognosis [64].

NE cells are characterized by expression of several neuronal as well as secretory markers, but the most prominent are the neuron specific enolase (NSE) and chromogranin A (CgA) [65]. NE cells do not express androgen receptor making them refractory to anti-androgen therapy [66-68]. Intriguingly, androgen deprivation can itself drive transdifferentiation of PCSC into NE cells [64]. In addition, NE cells can support the survival of other prostatic cells in their vicinity by allowing them to survive in the absence of androgens via secretion of trophic paracrine factors [68, 69]. Alternatively, NE cells can enhance the sensitivity of neighboring prostate cells to androgens such that they can survive in the presence of a much smaller concentration of androgens [70]. The NE cell population is highly resistant to conventional anti-mitotic agents and these cells also are resistant to undergoing apoptosis [71, 72]. Hence, NE transdifferentiation of prostate cancer stem cells could contribute to the failure of both hormonal as well as cytotoxic therapy in this disease [66-72]. While several approaches are under investigation to interfere with function of NE cells in prostate cancer [64], there are no treatments in the pipeline that could prevent transdifferentiation of PCSC into NE cells.

Neuroendocrine differentiation of small cell lung cancer is another interesting example. One theory for the origin of small cell lung carcinoma (SCLC) is that it arises from failure of lung tissue stem cells to completely differentiate into pulmonary neuroendocrine cells [73]. Aberrant methylation of NE cell lineage determining genes was found in SCLC [73]. At present, SCLC can almost never be fully eradicated with conventional approaches. Therefore, if tumor initiating cells in SCLC can be induced to transdifferentiate into post-mitotic NE cells, it might be possible to prevent recurrence of SCLC after conventional and/or targeted therapy.

### Vasculogenic mimicry

As tumors grow, their nutrient and oxygen requirements increase [1]. Classic angiogenesis is a process whereby the tumor secretes factors such as VEGF to recruit host's endothelial cells to form blood vessels for its nutrient needs. Interestingly, it was demonstrated that melanoma stem cells can themselves transdifferentiate and form vascular conduits that supply the tumor with blood [74]. This is referred to as "vasculogenic mimicry" (VM). It is not completely clear whether VM reflects the plasticity of differentiated melanoma cells or transdifferentiation of melanoma CSC. Nonetheless, many different pharmacologic interventions have been reported to inhibit VM in various cancers [75-81]. Among these, thalidomide, endostatin, and lycorine hydrochloride were shown to inhibit VM specifically in melanomas [80, 81]. Other compounds known to inhibit tumor VM either *in vitro* or in an *in vivo* mouse model, include: isoxanthohumol, endostar, zoledronic acid, curcumin, and a group of cell-permeable, phosphatase-stable phosphopeptide mimetic pro-drugs targeted to the SH2 domain of Stat3 [75-79].

### Adipocyte-like differentiation

It was demonstrated that specific unsaturated fatty acids, namely palmitoleic, oleic and linoleic acids, induce transdifferentiation in several different human cancers, including melanoma [82]. First, it was observed that conditioned media from human embryonic stem cells would cause adipocyte-like transdifferentiation. Subsequently, it was reported that a similar differentiation could be induced by treating melanoma spheres with unsaturated fatty acids and by upregulation of PPAR $\gamma$  [82]. This mechanistic understanding of transdifferentiation of melanoma CSC into adipocyte-like cells could open new therapeutic avenues.

### Epithelial mesenchymal transition (EMT): a transdifferentiation process that generates more CSC

EMT in cancer is the process through which epithelial cells of a tumor acquire invasive properties and migrate away from the primary lesion. Activation of the EMT program can confer on cancer cells the abilities of self-renewal and unlimited differentiation [18, 83, 84]. Hence, EMT can be considered a form of transdifferen-

tiation that generates CSC or tumor initiating cells. Another insight gained from this observation is that the inflammatory stromal conditions that give rise to EMT may be similar to those needed to maintain CSC in their respective niche [1]. EMT in cancer (and ways to combat it) is the subject of extensive research and has been recently reviewed [85, 86]. Thus, one consequence of inhibiting EMT in cancer would be to prevent transdifferentiation of tumor cells back into CSC.

### Conclusion

The CSC model of tumor pathogenesis explains why conventional cytotoxic therapies are rarely completely effective and recurrence of disease inevitably occurs. Hence, it is critical to define the precise markers of CSC that are present within specific cancers. As CSC phenotypes appear to be heterogeneous within each type of cancer and perhaps even vary from patient-to-patient, multi-pronged approaches including patient-specific approaches may be needed to eliminate CSC.

While CSC may contribute to the resistance of tumors to conventional therapies, their plasticity to differentiate may prove to be an Achilles' heel. One consequence of plasticity of CSC is their ability to undergo terminal differentiation/transdifferentiation. The goal is to exploit this vulnerability to deplete the CSC pool by inducing post-mitotic/ terminal differentiation or prevent such differentiation when it serves to enhance the tumor aggressiveness. Tumor transdifferentiation therapy is an area that has been inadequately explored. Accumulating evidence from multiple cancers now points to the potential of differentiation therapies. The time is ripe for a critical evaluation of such evidence and a concerted effort to develop novel treatments. Efforts are already underway to elucidate the mechanisms underlying EMT with the goal of inhibiting mesenchymal differentiation of tumor cells. With new insights gained from the CSC model, and armed with the knowledge that EMT is actually a way of generating CSC, it may eventually be possible to deplete the pool of CSC, prevent their renewal and achieve permanent remission.

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